George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

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Propulsive Small Expendable Deployer System (ProSEDS) Project Plan

ADVANCED SPACE TRANSPORTATION PROGRAM
TD15

SPACE TRANSPORTATION DIRECTORATE

ProSEDS PROJECT PLAN

TABLE OF CONTENTS

ProSEDS PROJECT PLAN

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LIST OF ACRONYMS

ASTP	**Advanced Space Transportation Program**
CDR	**Critical Design Review**
COC	**Certificate Of Compliance**
CWC	**Collaborative Work Commitment**
DIFP	**Differential Ion Flux Probe**
EEE	**Electrical, Electronic, And Electromechanical**
ELV	**Expendable Launch Vehicle**
EMI	**Electromagnetic Interference**
EWR	**Eastern Western Range**
GPMC	**Governing Program Management Council**
GPS	**Global Positioning System**
HVCM	**High Voltage Control Monitor**
IA	**Independent Assessment**
ISO	**Industrial Safety Office**
KSC	**Kennedy Space Center**
LEO	**Low Earth Orbit**
LPSP	**Langmuir Probe Spacecraft Potential**
MARTS	**Marshall Resource Tracking System**
MM	**MSFC Manual**
MMI	**MSFC Management Instruction**
MSFC	**Marshall Space Flight Center**
MQM	**Marshall Quality Manual**
NASA	**National Aeronautics And Space Administration**
NHB	**NASA Handbook**

NPD	**NASA Program Directive**
NPG	**NASA Procedures And Guidelines**
NRA	**NASA Research Announcement**
PCA	**Program Commitment Agreement**
PDR	**Preliminary Design Review**
PMC	**Project Management Council**
PMG	**Plasma Motor Generator**
PROSEDS	**Propulsive Small Expendable Deployer System**
RVC	**Requirements, Verification, Compliance**
SEDS	**Small Expendable Deployer System**
S&MA	**Safety And Mission Assurance**
STD	**Space Transportation Directorate**
TIPS	**Tether Physics And Survivability**
TSS	**Tethered Satellite System**
VRC	**Virtual Research Center**
WBS	**Work Breakdown Structure**
WIS	**Workforce Information System**

FOREWORD

This Project Plan describes the planning and objectives for the implementation of a NASA project known as the Propulsive Small Expendable Deployer System (ProSEDS). This plan has been prepared in accordance with the *NASA Program and Project Management Processes and Requirements*, NPG 7120.5A, and is consistent with the *NASA Strategic Management Handbook* and *NASA Program/Project Management*, NPD 7120.4. In addition, it follows the MSFC Lead Center Implementation Plan for Space Transportation System Development and Technology Programs.

I. INTRODUCTION

NASA began developing tether technology for space applications in the 1960's for the Apollo Program. Important recent milestones include retrieval of a tether in space (TSS-1, 1992), successful deployment of a 20-km-long tether in space (SEDS-1, 1993), and operation of an electrodynamic tether with tether current driven in both directions for power and thrust modes (PMG, 1993). A complete list of missions is shown in Table I.

Table I: Known Tether Flights (see Note).

NAME	DATE	ORBIT	LENGTH	COMMENTS
Gemini 11	1967	LEO	30 m	spin stable 0.15 rpm
Gemini 12	1967	LEO	30 m	local vertical, stable swing
H-9M-69	1980	suborbital	500 m	partial deployment
S-520-2	1981	suborbital	500 m	partial deployment
Charge-1	1983	suborbital	500 m	full deployment
Charge-2	1984	suborbital	500 m	full deployment
ECHO-7	1988	suborbital	?	magnetic field aligned
Oedipus-A	1989	suborbital	958 m	spin stable 0.7 rpm
Charge-2B	1992	suborbital	500 m	full deployment
TSS-1 (Retrieved)	1992	LEO	< 1 km	electrodynamic, partial deploy, retrieved
SEDS-1	1993	LEO	20 km	downward deploy, swing & cut
PMG	1993	LEO	500 m	electrodynamic, upward deploy
SEDS-2	1994	LEO	20 km	local vertical stable, downward deploy
Oedipus-C	1995	suborbital	1 km	spin stable 0.7 rpm
TSS-1R	1996	LEO	9.6 km	electrodynamic, severed
TiPS	1996	LEO	4 km	long life tether, on-orbit (11/96)

Note: Most have been completely successful, the most relevant of which are the SEDS, PMG and TiPS missions.

Various types of tethers and systems can be used for space transportation. Long non-conducting tethers can be used to exchange momentum between two masses in orbit. Shorter electrodynamic tethers can use solar power to 'push' against a planetary magnetic field to achieve propulsion without the expenditure of propellant. The ProSEDS mission will utilize the latter by demonstrating electrodynamic drag thrust of a Delta II upper stage. The physical principles involved are described below:

Electrodynamic tether thrusters work by virtue of the force a magnetic field exerts on a wire carrying an electrical current. This phenomenon was first studied around 180 years ago, and the equation that governs the force has long been known. The effect is the basis for electric motors and generators.

Although the working principle of electrodynamic tether thrusters is not new, its application to space transportation will be revolutionary. In essence, an electrodynamic tether thruster is just a clever way of getting an electrical current to flow in a long orbiting wire (the tether) so that the Earth's magnetic field will accelerate the wire and, consequently the payload attached to the wire. The direction of current flow (down or up the tether) determines whether the magnetic force will raise or lower the orbit.

An electrodynamic tether generates and forms part of a unique type of electrical circuit, which has been successfully demonstrated in space. The tethered system extracts electrons from the ionospheric plasma at one end (upper or lower) and then carries the electrons through the tether to the other end, where it returns them to the plasma. The circuit is completed by currents in the plasma. The net force caused by a uniform magnetic field acting on a current-bearing closed loop of wire (i.e., a normal circuit) would be zero, as the force on one length of wire would be canceled by that on another in which the current was flowing in the opposite direction. However, since there is no mechanical attachment of the tethered system to the plasma (which is just the rarefied medium through which the system is traveling), magnetic forces on the plasma currents do not affect the tether motion. In other words, a length of wire with a unidirectional current flowing in it, is accelerated by the Earth's magnetic field.

The bias voltage of a vertically deployed metal tether, which results just from its orbital motion (assumed eastward) through the Earth's magnetic field, is positive with respect to the ambient plasma at the top and negative at the bottom. Thus, the "natural" current flow is the result of negative electrons being attracted to the upper end and then returned to the plasma at the lower end. The magnetic force in this case has a component opposite to the direction of motion, and thus leads to a lowering of the orbit and eventually to re-entry. The basic physics was verified to work in space by the TSS-1R and PMG missions, but no measurements were made to quantify the resulting orbital changes nor was the high-current bare tether concept demonstrated. Figure 1 illustrates each step in the process.

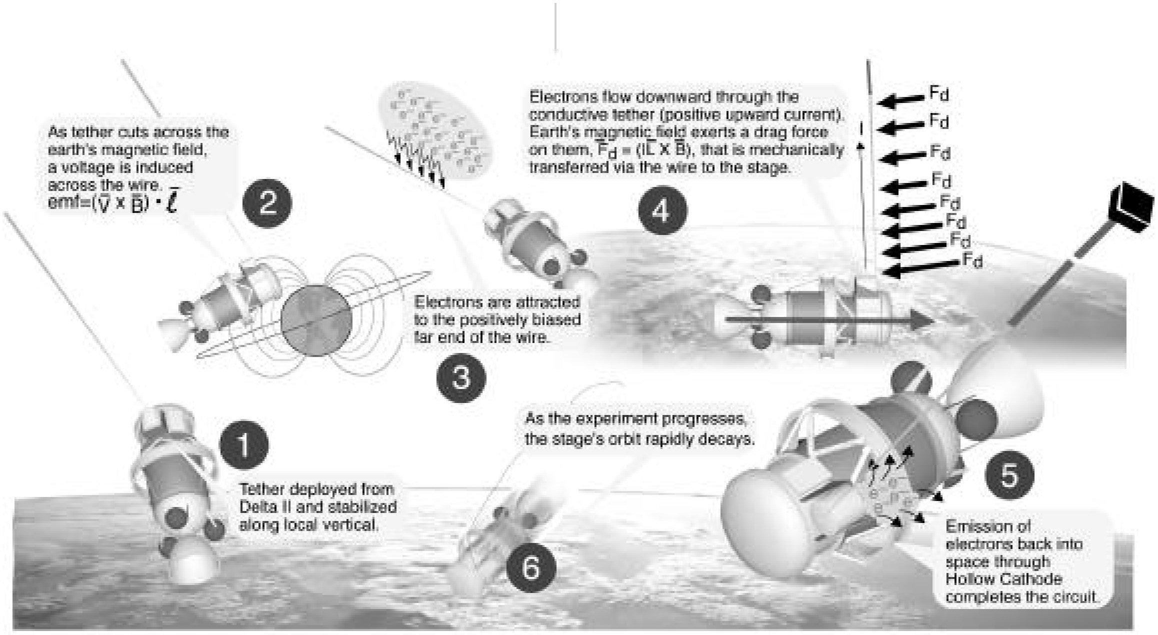


Figure 1. Overview of the Electrodynamic Tether Propulsion Process

The motion of the system through the Earth's magnetic field induces a voltage $emf = \mathbf{L}\cdot(\mathbf{v}\times\mathbf{B})$ between the two ends of the conductive tether, where $\mathbf{L}$ is a vector parallel to the tether and whose magnitude is the length of the conductive tether, $\mathbf{v}$ is the velocity of the system through the ionosphere, and $\mathbf{B}$ is the local value of the Earth's magnetic field vector.

The current in the tether varies along its length, since collected electrons accumulate in an increasing downward stream in the wire. Denoting the current in a segment of tether $\Delta\ell$ at a distance ℓ from the lower end of the tether by $I(\ell)$, the drag force on this tether segment $\mathbf{F}_d(\ell) = I(\ell)\Delta\vec{\ell}\times\mathbf{B}$, where $\Delta\vec{\ell}$ points in the direction of the current flow. The total drag force on the system is then the sum of the $\mathbf{F}_d(\ell)$ over the full tether length.

To get an orbit-raising thrust, a current in the opposite direction must be obtained. This requires a reversal of the natural electrical bias (i.e., that due to the motion through the magnetic field) by means of an electrical power supply, which can, of course, use solar energy. PMG has successfully demonstrated this mode of operation using batteries, though no thrust measurements were made.

One of the most important features of electrodynamic tether thrusters is that no on-board power source is required to drive the electrical current flow in either the orbit-raising or orbit-lowering mode. Sources inherent to Earth orbit are used. To raise the orbit, the natural energy of the Sun can be converted to the electrical energy required to drive the tether current. To lower the orbit, the orbital energy itself (supplied by the Earth-to-orbit launcher when it raises the system into orbit) is the energy source of the tether current. ProSEDS will operate in the orbit-lowering mode. Rather than dissipating all the electrical energy it generates in its operation, ProSEDS will use some of it to recharge batteries, thus greatly extending mission lifetime.

The previously cited electrodynamic tether missions, while verifying that the basic principles of electrodynamic tether operation are sound, did not establish scalability of electrodynamic tether to useful applications. ProSEDS aims to do this through the use of a more efficient current collection design, which, when properly scaled, should allow currents of 10 A or more with relatively short (~10 km) tethers suitable for applications such as ISS reboost and orbit modification of LEO payloads.

For ProSEDS, the electron expulsion task will be handled by a hollow cathode device, which requires a small amount of gas to operate. In future applications, Field Emitter Arrays (FEAs) may eliminate the need for even this consumable.

Collecting electrons from the ionosphere proves to be much more difficult than expelling them into it. Previous electrodynamic tether experiments have relied on either a large metallic surface (TSS-1R satellite) or a hollow cathode (PMG) to collect electrons from the ionosphere. PMG currents were disappointing. Achieving higher currents by satellite surface collection requires ever larger satellites, as a law of diminishing returns quickly sets in.

ProSEDS will use a radically different collection scheme, which promises to be much more efficient and easily scaleable to practical applications such as magnetic thrust. Most of the metallic tether will be left exposed to the plasma, rather than covered with an insulating sleeve as in previous electrodynamic tether missions. The bare tether itself will collect electrons directly. A well developed theory of current collection by thin wires, verified in plasma chamber tests (most recently at MSFC), indicates that the ProSEDS tether will be an order of magnitude more efficient in electron collection than what has been seen in previous space experiments, with even greater enhancements possible in the future. Before proceeding to the design of an operational system, however, the bare tether design must be tested in LEO. So far, neither theory nor lab tests have modeled the effects of the motion of the tether through the plasma. While there is no obvious reason why this should significantly affect the current collection, the bare tether’s performance in space should be verified with a real deployed tether system. ProSEDS will provide that verification, and the data collected by the various ProSEDS instruments will thoroughly characterize the space environment, thus giving analysts a chance to determine the reasons for any deviations from predicted performance.

ProSEDS will shatter previous records for current collection by a tether in space and show a dramatic increase in the rate of orbital decay over a tether-less system. The basic physics of current collection is the same in either mode of operation. Thus, ProSEDS will serve to verify the bare tether design concept for both orbit-raising and orbit-lowering applications.

II. PURPOSE, SCOPE AND OBJECTIVES

A. Purpose

The ProSEDS Experiment will demonstrate conclusively the use of electrodynamic tethers for generating significant thrust in space by decreasing the orbital altitude of a Delta II Expendable Launch Vehicle (ELV) upper stage.

B. Scope

The ProSEDS experiment hardware will be integrated on the Delta II upper stage as were the previous SEDS missions. Once the primary payload is deployed, a timer will initiate the deployment of the ProSEDS tether (up to 20.1 km in length), thus initiating the experiment. Current collection and thrust generation will begin as soon as the 5-km conducting portion of the tether completes deployment. On-board instrumentation and ground tracking systems will begin measuring system performance as the Delta stage begins to lose altitude. The primary objective demonstrating significant thrust over a wide range of conditions will be achieved in the first 16 orbits, but the instruments will monitor system performance until it either re-enters or ceases to function.

C. Objectives

The specific objectives and performance goals of the ProSEDS experiment are listed in Table II.

Table II. Objectives and Specific Performance Goals of the ProSEDS Experiment.

OBJECTIVES	CRITERIA FOR SUCCESS (PERFORMANCE METRICS)	MEASUREMENTS REQUIRED	INSTRUMENTS REQUIRED
(Primary 1) Demonstrate significant, measurable electrodynamic tether thrust in space.	Demonstrate an orbital decay rate of at least 5 km per day.	Change Of Orbital Position.	GPS Ground RADAR
(Primary 2) Measure the current collection performance of the bare electrodynamic tether under varied ionospheric conditions and determine its scalability to future applications.	Obtain data over 16 orbits. (Obtain continuous data for the first 3 orbits and sampling over the remaining 13.)	Voltage Current Magnetic Field Orientation Spacecraft Potential Plasma Density Ambient Electron Temp Absolute position of Delta Relative position of Tether (est)	Voltmeter Ammeter Aspect Magnetometer DIFP, Langmuir Probe Langmuir Probe, DIFP Langmuir Probe GPS, Ground RADAR Turns Counter

OBJECTIVES	CRITERIA FOR SUCCESS (PERFORMANCE METRICS)	MEASUREMENTS REQUIRED	INSTRUMENTS REQUIRED
(Secondary 1) Demonstrate the regulation, storage, and use of tether generated electrical power.	Observe an increased state of charge in the battery or a slower battery discharge rate than is predicted by the actual loads.	Battery Temperature Voltage Current	Thermistor Voltmeter Ammeter
(Secondary 2) Determine system performance during the extended mission phase (begins after orbit 16).	Collect available tether performance data.	Telemetry (if available) Change of Orbital Position	All functioning instruments GPS, Ground RADAR
(Secondary 3) Assess tether survivability in AO, meteoroid, and orbital debris environment.	Observe tether integrity.	Tether observation(s) Voltage Current	GPS, RADAR Voltmeter Ammeter
(Secondary 4) Assess tethered system dynamics during electrodynamic operation	Stable (bounded) dynamic envelopes	Endmass relative position and Delta attitude versus time	GPS Magnetometer

III. CUSTOMER DEFINITION AND ADVOCACY

The primary customers for the ProSEDS experiment are NASA's Advanced Space Transportation Program (ASTP), and the Pathfinder Program Office. ASTP is interested in the development and test of technologies that will potentially provide low-cost space transfer, have low development costs, and that will show near-term results. The Pathfinder Program Office is funding the ProSEDS project through the Future-X NRA 8-21. Frequent interaction with the Pathfinder Program manager will be conducted to ensure continued advocacy for the project. The following companies have indicated interest and endorsement of the ProSEDS experiment: TRW, Lockheed Martin, Boeing North American, Orbital Science Corporation, Spectrum Astro, and Tethers Unlimited. These companies have interest in the application of electrodynamic tethers both for reducing orbital debris, and for lowering the in-space propulsion costs of future systems. In addition, the Air Force Research Lab has also expressed interest in the technology to be demonstrated by ProSEDS, and are collaborating on the project. Frequent interaction with Future-X program managers will be conducted to ensure their continued advocacy for the project.

IV. PROJECT AUTHORITY

The *NASA Strategic Plan* and the *NASA Strategic Management Handbook* assign to MSFC the Lead Center responsibility for Space Transportation Systems development. This assignment includes Lead Center responsibility for the Advanced Space Transportation Program of which the ProSEDS Project is a part. The Space Transfer Technology Project Office, in the

Advanced Space Transportation Program Office, is responsible for project implementation and management. The Kennedy Space Center, ELV and Payload Carriers Programs Office is responsible for the interfaces, contract, launch approval, and launch operations of the Delta II launch vehicle. The MSFC GPMC is responsible for oversight of the ProSEDS Project.

V. MANAGEMENT

A. Organization and Responsibilities

1. NASA Headquarters

The Office of Aero-Space Technology (Code R) is the NASA Headquarters office responsible for the ProSEDS experiment. The Office of Space Flight (Code M) is responsible for the Delta launch manifest.

2. Field Centers

The field centers involved in the ProSEDS experiment include: George C. Marshall Space Flight Center; and Kennedy Space Center. The involvement of each center is described below:

a. George C. Marshall Space Flight Center (MSFC)

The MSFC, as the lead center for Space Transportation Systems Development and the Center of Excellence for Space Propulsion, is the principal NASA Center for research, technology maturation, design, development, and integration of space transportation and propulsion systems, including both reusable and expendable launch vehicles, and vehicles for orbital transfer and deep space missions.

The Advanced Space Transportation Program, X-33, and Future-X/Pathfinder Program Offices have been consolidated with other space transportation development and technology activities at the MSFC into a new organizational unit, the Space Transportation Directorate. This consolidation enables integrated coordination of ongoing advanced space transportation activities together with strategic planning for new initiatives, and will provide a single focal point for the lead center responsibilities within the mission area of space transportation. The Space Transportation Directorate is responsible for executing the NASA Lead Center role assigned to MSFC for space transportation systems development activities. The Directorate integrates program and project level planning, research, and development to ensure a well balanced space transportation development program that meets the Agency's aggregate needs in a coordinated and integrated manner.

The manager of the Advanced Space Transportation Program, manages and integrates activities for conducting research and technology maturation and demonstrations applicable to advanced space transportation systems.

The ProSEDS experiment is one of the experiments selected under the Future-X NRA, in the Pathfinder Program Office, and has been specifically assigned to the Space Transfer Technology Project Manager. The Space Transfer Technology Project Manager serves a dual function as ProSEDS Project Manager.

The ProSEDS Project Manager has a team consisting of members of involved Directorates/Organizations within MSFC, representatives from other involved centers, other government agencies, industry, and academia. This team is responsible for planning, coordinating and interfacing with other projects and organizations as appropriate to accomplish the job. The team organization for ProSEDS is shown in Fig. 2.

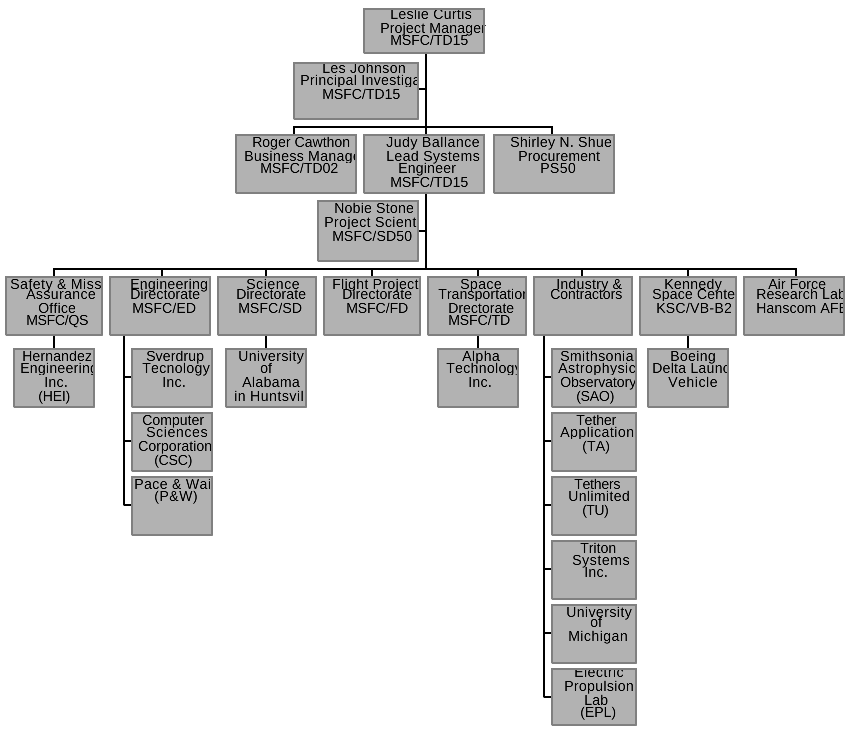


Figure 2. ProSEDS Project Organization

b. Kennedy Space Center (KSC)

The KSC ELV and Payload Carriers programs Office shall provide the interface to the Delta II launch vehicle. Delta interfaces, launch approval, launch site activity and launch operations shall be worked through KSC. The mission is manifested for launch, no earlier than August 2000 aboard a GPS IIR mission.

B. Special Boards and Committees

Program Advisory Council
An integral element of the Lead Center Program Management Council is the Program Advisory Council. The Program Advisory Council is chaired by the Advanced Space Transportation Program Manager and consists of the various Program Managers and appropriate Headquarters and Support Centers personnel.

C. Management Support Systems

The following management systems will be utilized with the ProSEDS experiment. In addition, other systems within the agency are being reviewed and considered as potentials.

1. Marshall Resources Tracking System (MARTS)
The MARTS system for tracking funding authority, commitments, obligations, cost and disbursements will be utilized by ProSEDS.

2. Workforce Information System (WIS)
The WIS system will be utilized for tracking the civil service workforce associated with ProSEDS.

3. Automated Procurement Request System (APRS)
The S&E APRS system will be used for the Procurement Requests (Form 424) process.

4. Virtual Research Center (VRC)
The VRC is an Internet-based project management and document management system that allows all project team members access to project documents, drawings, meeting notes, assigned action items and the group calendar.

5. Other Management Systems
Current plans call for the implementation by June 1, 2000 of the Integrated Financial Management Planning (IFMP) system. This is a mandatory, agency wide tool for budgeting, tracking and analyzing funding.

VI. TECHNICAL SUMMARY

The ProSEDS project encompasses the definition, design, fabrication, assembly, test, checkout, flight and data analysis of an electrodynamic tether propulsion system flown as a secondary payload on a Delta II launch vehicle. The primary payload will be an Air Force payload, a Global Positioning System (GPS) satellite. Since this will be a replacement mission for the Air Force, GPS IIR, the actual launch date is not know, but will be called-up about 6 months prior to launch. The mission that ProSEDS will be manifested on will not be earlier than August of 2000. The ProSEDS experiment will utilize an advanced electrodynamic tether capable of achieving a higher thrust with a significantly shorter length and no active current collection device, hence making the system much less expensive and simpler to operate than previous systems (i.e., TSS). The ProSEDS Experiment will demonstrate conclusively the use of electrodynamic tethers for generating significant thrust in space by decreasing the orbital altitude of the Delta II Expendable Launch Vehicle (ELV) upper stage.

A. Project Requirements

The ProSEDS project requirements are consistent with the mission objectives list in Section I of this plan.

B. System Requirements

The ProSEDS system level requirements are specified in the ProSEDS Requirements, Verification and Compliance Database (RVC). The RVC formally defines and documents the requirements for the design, development, testing and operation of the ProSEDS experiment. The RVC provides the requirements necessary to achieve mission success according to the objectives stated in this project plan document. The RVC also covers the verification and compliance of the ProSEDS requirements.

C. System Constraints

The ProSEDS project is a fixed-price effort and is therefore constrained to fit within its funding allocation. Any changes in scope will be handled in a manner consistent with the ProSEDS proposal to Future-X.

D. Ground Systems and Support

Ground systems and support requirements for the ProSEDS flight and GSE equipment are defined in the ProSEDS RVC. The ProSEDS experiment team will perform prelaunch integration and testing of the experiment at the Delta II range facilities. The ProSEDS experiment will be shipped to the Eastern Range facilities at Kennedy Space Center prior to Delta II integration.

E. Facilities

Existing facilities will be utilized at MSFC. In addition the Delta II Range at KSC will be used.

F. Logistics

The ProSEDS logistics activities will be integrated with other disciplines and functions to assure cost effective support for the project. Logistics planning and implementation will be tailored specifically to ProSEDS project requirements.

G. Mission Results Analysis and Reporting

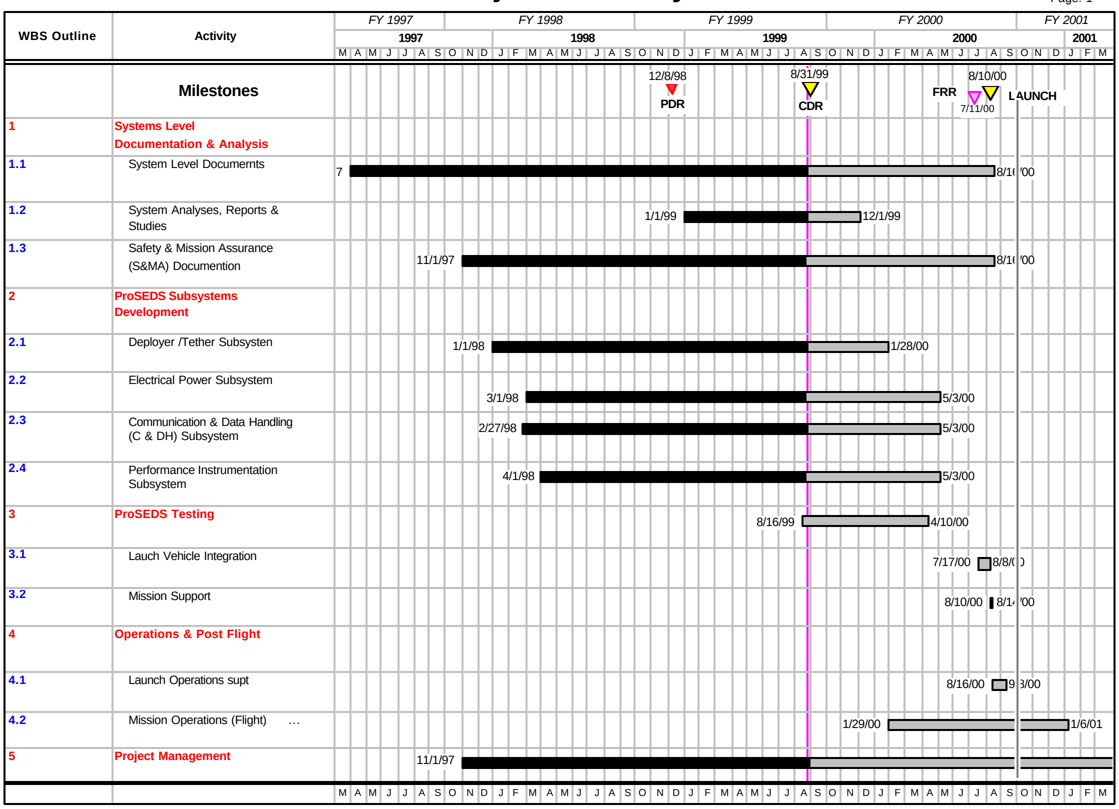
Data obtained from the experiment will be distributed in near-real time using the Internet. Selected team members will receive funding for limited post-flight data analysis. NASA technical reports, conference and journal publication will be encouraged. Management at all relevant levels will be appraised of mission results.

VII. SCHEDULES

The ProSEDS summary schedule dated August 31, 1999 is shown below. This is a representative schedule. A current schedule is posted in the ProSEDS wing of the Virtual Research Center.

ProSEDS Project Summary Schedule

31 Aug 99
Page: 1



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VIII. RESOURCES

A. Funding Requirements (NOA in Millions)

	FY99	FY00	FY01	TOTALS
TOTAL	3.929M	2.229M	0.451M	6.609M
Proj. Mgmt:	0.028	0.029	0.000	0.057
System Eng:	0.577	0.540	0.000	1.117

Subsys.Dev:	3.305	1.568	0.009	4.882
Veh. Integra:	0.014	0.041	0.000	0.055
Operations:	0.005	0.051	0.000	0.056
Post Flight:	0.000	0.000	0.442	0.442

B. Institutional Requirements (FTE)

FY99	FY00	FY01	Totals
25.2	23.0	2.1	50.3

IX. CONTROLS

The ProSEDS project is subject to the controls as contained in NASA Procedures and Guidelines, NPG 7120.5A, effective April 3, 1998. Responsibilities for Program and Project Management are as follows:

A. Headquarters Responsibilities

Associate Administrator for Aeronautics and Space Transportation Technology

a. Providing program advocacy.
b. Establishing program requirements and metrics.
c. Recommending the level of GPMC oversight for each new program.
d. Assigning program and selected project responsibilities to Lead Centers.
e. Recommending new programs to the Agency PMC.
f. Developing, coordinating, and maintaining the PCA.
g. Approving Program Plans.
h. Assessing program performance against requirements and customer expectations.
i. Ensuring timely resolution of multiple program and project issues with assigned enterprise.
j. Serving as a member of the GPMC.
k. Allocating budgets to programs.

B. Center Responsibilities

1. The Lead Center Director (MSFC)

a. Serving as Chairperson of Lead Center PMC.
b. Supporting the Associate Administrator of Aeronautics and Space Transportation Technology in program formulation.
c. Providing overall direction, control, and oversight of program implementation.
d. Appointing the program manager.

e. Concurring on the Program Plan for Associate Administrator approval.
f. Assigning work to other Centers.
g. Integrating institutional resources with program needs.
h. Coordinating cross-Center activities.
i. Ensuring compliance to policy/standards.
j. Maintaining dual path for Quality and IA.
k. Developing and maintaining program/project implementation policies and procedures compliant with NPD 7120.4, NPG 7120.5A, and ISO 9000.

2. Performing Center Director (MSFC)

a. Performing advanced concept studies in support of Agency and enterprise strategic plans.
b. Supporting the program formulation.
c. Approving Project Plan.
d. Appointing the Project Manager.
e. Project implementation and oversight.
f. Developing and maintaining program/project implementation policies and procedures compliant with NPD 7120.4, NPG 7120.5A, and ISO 9000.

3. Future-X/Pathfinder Program Manager

a. Program planning, including: recommendation of program objectives, requirements, implementation guidelines, program integration, budget and milestones, and preparation of Program Plans and PCA's.
b. Developing, recommending, and advocating the program resources.
c. Execution of the Program Plan and oversight.
d. Approving Project Plans and associated changes to these documents.
e. Reviewing and reporting program/project performance.
f. Establishment of project requirements and performance metrics.
g. Allocating budget to projects.
h. Control of program changes.
i. Establishing support agreements.

4. The ProSEDS Project Manager

a. Supervision of the Project
b. Preparation and maintenance of the Project Plan, specifications, schedules, and budgets.
c. Acquisition and utilization of participating contractors.
d. Execution of the Project Plan.
e. Reporting project status.
f. Approving Collaborative Work Commitments (CWCs).
g. Conducting design and all other appropriate reviews.
h. Participation in Configuration Control Board Activity.

5. The ProSEDS Principal Investigator is responsible for:

a. Approving the instrument specification
b. Consulting and advising the Lead Systems engineer in development and fabrication.
c. Participating in inspection and acceptance of the instruments.
d. Supporting the development of test and operations plan.
e. Approving experiment objectives.
f. Participating in design reviews and all other appropriate reviews.
g. Reviewing and concurring in design changes and design reviews as required.
h. Participating in configuration control board actions.
i. Participating in the development of system requirements and approving changes that affect the experiment objectives.
j. Participating in subsequent test and evaluation processes incident to integration and flight preparation.
k. Leading analysis and interpretation of the data with emphasis on its utilization to future mission and applications.

6. The ProSEDS Lead Systems Engineer

a. The technical aspects of the ProSEDS project.
b. Development of the CWCs with the MSFC Organizations.
c. Development of the ProSEDS System Requirements.
d. Development of the Test and Operational Plans.
e. Development of the WBS.
f. Approving and concurring in design changes.
g. Leading the configuration control board.
h. Leading design reviews and team meetings as required.
i. Consulting and advising the Project Manager and Principal Investigator.
j. Approving the test program.
k. Approving final inspection and acceptance.
l. Leading integration and flight preparation.
m. Reviewing analysis and interpretation of data.

X. IMPLEMENTATION APPROACH

An In-House implementation mode will be utilized. MSFC will be responsible for accomplishing not only the overall Project Management but also doing the project Systems Engineering and Integration. This approach was selected because significant hardware already exists to accomplish the ProSEDS experiment. Hardware piece parts and engineering analyses only will be procured. Descriptions of responsibilities outlined below do not negate any previously agreed to Collaborative Work Commitments (CWCs), contract, or grant.

A. MSFC Support

The MSFC responsibilities are described below. Specific support is documented in the CWCs which have been developed for all internal MSFC tasks.

Space Transportation Directorate is responsible for project management, lead systems engineering and principle investigator functions for the project. STD is also responsible for developing and maintaining the ProSEDS system requirements, verification, and compliance database (RVC). STD will perform tether dynamics analyses, support development, testing, qualification of experiment software, support the development and qualification tether deployment testing and perform data analysis for deployment tests.

The Engineering Directorate, specifically the Avionics Department (ED10) will be responsible for providing membership to design teams, and working groups. ED10 will perform the design, development, and delivery of the ProSEDS flight power subsystem. This subsystem includes the primary battery, secondary battery, and the power distribution boxes. ED10 will design and deliver the flight cables. ED10 will support magnetometer and GPS testing. ED10 will support the analysis of the power system. ED10 will provide support in the selection of EEE parts. ED10 will develop, integrate and test the electrical power system including the power distribution busses. ED10 will perform functional testing on the power subsystem, GPS and magnetometer. ED10 will support the environmental testing of the power subsystem. ED10 will provide inputs to system level and environmental level test procedures. ED10 will design, develop, integrate and test the RF transmitter/antenna subsystem. ED10 will provide inputs to the launch site test plan and launch site facility requirements.

The Engineering Directorate, specifically the Structures, Mechanics, & Thermal Department (ED20) will be responsible for providing membership to design teams and working groups. ED20 will be responsible for the structural design of the flight system elements. ED20 will generate a dynamic finite element model (FEM) of the ProSEDS system with documentation. ED20 will do a modal test to correlate the dynamic FEM. ED20 will provide stress analysis, venting analysis and thermal analysis as required. ED20 will design the support structure for new ProSEDS flight hardware items. ED20 will provide vibration/modal facilities, vibration fixtures, and required acceleration measurements. ED20 will generate the random vibration criteria and perform qualification analyses and tests on the ProSEDS system. ED20 will support system level thermal vacuum testing, test integration, including test procedures and perform functional, acceptance and qualification tests as well as support post-ship off-line and integration with the launch vehicle. ED20 will support development of test procedures and test plan. ED20 will provide mission data reduction and analysis support, design review and configuration control support.

The Engineering Directorate, specifically the Materials Processes and Manufacturing Department (ED30) will be responsible for supporting the definition of system requirements, prescribing materials and processes consultation, supporting development of operating plans, test plan, verification plans, procedures and schedules. ED30 will interpret technical designs and review and evaluate materials usage applications. ED30 will support design teams and safety analyses as required. ED30 will provide a specification for the metallic and non-conductive tethers. ED30 will support development of tether splicing processes and provide particulate contamination control assistance. ED30 will participate in characterization testing of the plasma contactors. ED30 will provide AO emissivity, and strength testing on tether candidate materials. ED30 will support tether deployment test.

The Engineering Directorate (ED), specifically the Engineering Systems Department (ED40) is responsible for Configuration Management for ProSEDS. ED40 will provide membership to design teams, working groups, safety teams, and configuration control functions. ED40 will develop and maintain an electrical power and energy management report, and a mass properties data base for ProSEDS. ED40 will generate periodic mass properties status reports, perform pertinent EMC/EMI analyses and natural environment & effects analyses. ED40 will develop and maintain Natural Environment & Effects sections of ProSEDS system specification and will develop the ProSEDS EMC requirements for input into the system specification. ED40 will perform ProSEDS tether development testing and Electromagnetic Interference testing. ED40 will provide orbital debris reports, both post PDR and pre-CDR reports.

The Science Directorate, specifically the Space Science Department (SD50) will be responsible for definition, development, design, stress analysis and testing of plasma probe instrumentation (DIFP/M). They are also responsible for the stress analysis of the DIFP/M sensors and brackets. SD50 will perform plasma chamber tests on selected samples of wire or conductive tether materials. SD50 will develop a ProSEDS measurement and instrumentation requirements documentation and specification. They will support development of ProSEDS systems that interface with or affect performance instrumentation.

The Science Directorate, specifically the Microgravity Science & Applications Department (SD40) will support tether deployment testing and other ProSEDS hardware testing. SD40 will support development of test procedures and Launch site test plans, including ground support equipment requirements.

The Flight Projects Directorate, specifically the Ground systems Department (FD40) will be responsible for the ProSEDS operations and data plan.

Safety and Mission Assurance (S&MA) Office (QS) will provide safety analysis for the ProSEDS system and components. A Quality Plan will be written and maintained by S&MA to identify the quality requirements for the project. The organization will also insure that required inspections, test and quality records are defined and documented.

B. Contracted Support

1. Alpha Technologies

Alpha Technologies will be responsible for performing the following tasks:

a. ProSEDS System Engineering Support;
b. ProSEDS Data System Flight Software Verification & Validation Plan;

c. ProSEDS Data System Flight Software Requirements Development, Documentation, and Review;
d. ProSEDS Data System Flight Software Development, Documentation, and Review;
e. ProSEDS Data System Flight Software Independent Verification & Validation;
f. ProSEDS Data System Electronics Box Development & Test;
g. Global Positioning System (GPS) Receiver Box Design & Preliminary Tests;
h. Sustaining Engineering, Test, and Integration Support;
i. Mission Support & Post Flight Evaluation.

2. Colorado State University

Colorado State University will provide testing of the hollow cathode plasma contractor.

3. Electric Propulsion Laboratory, Inc.

Electric Propulsion Laboratory will provide the following Hollow Cathode Plasma Contractor Subsystem hardware: engineering model plasma contractor hollow cathode unit, in-vacuum functional model plasma contractor test pallet, flight plasma contractor hollow cathode component, flight plasma contractor hollow cathode gas feed component, and flight plasma contractor hollow cathode power electronic unit component.

4. Smithsonian Institution Astrophysical Observatory

Smithsonian Institution Astrophysical Observatory will be responsible for performing the following tasks:

a. Mission Analysis;
b. Provide Inputs to System Engineering;
c. Electro-thermo-dynamic integrated simulations;
d. Dynamics and Control of Deployment;
e. Collection Models;
f. System Performance Parametric Analysis;
g. Coordination of Tether Development and Testing
h. Development of Software for Data Interpretation;
i. Mission Operations;
j. Post-flight Data Analysis;
k. Performance Estimation Model
l. Analysis of tethered systems.

5. Tether Applications

Tether Applications will design, fabricate, test, and deliver prototype and flight deployer, brake, and tether subsytems.

6. Tethers Unlimited

Tethers Unlimited will be responsible for the development of a long-lived tether as an optional system for the ProSEDS Mission.

7. Triton Systems, Inc.

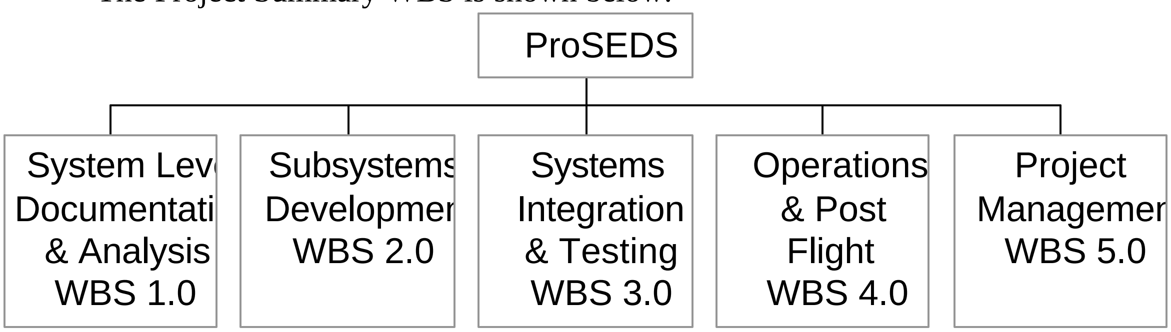
Triton Systems will be responsible for the development of insulating and conducting coatings for a development and flight tether.

8. The University of Michigan

University of Michigan will be responsible for the following tasks: the endmass for the ProSEDS experiment, the High Voltage Control Monitor (HVCM), the Langmuir Probe and Spacecraft Potential (LPSP) Instrument, the performance measurement system design, the high voltage performance analysis, and post flight data analysis.

C. Project Summary WBS

The Project Summary WBS is shown below:



XI. ACQUISITION SUMMARY

The ProSEDS experiment acquisition strategy is based on both NASA in-house and contracted activities. All of the planned individual contracts are currently anticipated to be less than $10M. Because of the experimental nature of the ProSEDS and tight time schedules, every emphasis will be placed on short procurement approaches. Existing contracts, NASA Research Announcements, Purchase Orders, and Support Agreements will be utilized to the greatest extent possible. All planned procurements, noted in Table III, and the associated technical monitoring, will be accomplished by Marshall Space Flight Center.

Table III. Planned Procurements and Monitoring for the ProSEDS Experiment.

ELEMENT	TYPE PROCUREMENT	TYPE CONTRACT	SOURCE
Engineering Design	Competitive NRA	Grant	University

Hardware Development (HVCM/LPSP)	Competitive NRA	Cost-Reimb.	University
Hardware Development (End Mass)	Competitive NRA	Cost-Reimb.	University
Data System Electronic Box Hardware & S/W	Competitive NRA	FFP	Contractor
Mission Analysis	Competitive NRA	Grant	University
In-Vacuum Functional Model Plasma Test Pallet Up-Grade for Interface Testing	Competitive NRA	FFP	Contractor
Testing of Hollow Cathode Plasma Contactor	Competitive NRA	Cost-Reimb.	University
Design, Fabricate, Test & Deliver Prototype & Flight Deployer, Brake & Tether Subsystems	Competitive NRA	FFP	Contractor
Develop A Long -Lived Optional Tether	Competitive NRA	FFP	Contractor
Devel. Insulation & Conductive Tether Coatings	Competitive NRA	FFP	Contractor
Thermal Analysis & Design	Competitive	Cost-Reimb.	Onsite Spt. Contractor

XII. PROGRAM/PROJECT DEPENDENCIES

The technology to be demonstrated with ProSEDS has multiple applications across many NASA organizational offices and the NASA Strategic Enterprises. Table IV summarizes the relationship between ProSEDS and other programs (NASA and non-NASA).

Table IV. Relationships Between the ProSEDS and Other Programs.

Related Application	Program Supported	Status
Tethers for Propulsion and Power at Jupiter	Europa Orbiter and/or Jupiter Polar Orbiter	concept study complete
Electrodynamic Reboost of the International Space Station	International Space Station	concept study complete
Electrodynamic Reboost of the Space Based Laser Demonstrator	Ballistic Missile Defense Organization, Space Based Laser Program	concept study begun
End-of-life deorbit of spacecraft and upper stages	Commercial	private company is marketing

XIII. AGREEMENTS

A. Internal NASA Agreements

MSFC has been assigned as the Lead Center for the Space Transfer Technology Project and is responsible for project implementation and management. Under agreement between

ASTP and the Pathfinder Program Office the ProSEDS Project will be managed under the Space Transfer Project, in ASTP.

B. External Agreements

The ProSEDS Project has external agreements with Universities, and Contractor through grants and contracts. All external agreements have been determined by competition as part of the overall acquisition strategy.

XIV. PERFORMANCE ASSURANCE

Quality

A quality plan will be prepared for the ProSEDS Project. ProSEDS flight hardware designed, developed and built in-house at MSFC will be in accordance with the MSFC-P02.1-CO2, Marshall Quality Manual (MQM). In-house hardware may be built to dated drawings with the approval of the Lead Systems Engineer and the Lab lead, as specified in the ProSEDS Configuration Control Plan. As built drawings will be submitted to the MSFC Configuration Control Process as specified in the ProSEDS Configuration Control Plan.

Due to the limited scope of the ProSEDS flight demonstration experiment, flight hardware may be commercial off-the-shelf as long as it meets the requirements specified in the ProSEDS Systems Specification. ProSEDS flight hardware purchased from outside vendors is not required to be ISO 9000 compliant. ProSEDS flight hardware purchased from outside vendors will be based on the specific requirements of NHB 5300.4(1C). Tailoring of these requirements will be reflected in the ProSEDS Quality Plan and/or in the vendor purchase order/contract. ProSEDS flight hardware purchased from outside vendors must be delivered with a Certificate of Compliance (COC) and an acceptance data package as specified in the purchase order or contract.

Quality record activities will be performed in accordance with MSFC-P16.1, Control of Quality Records. The project manager will be custodian of these records.

XV. RISK MANAGEMENT

Risk Management began in the formulation phase of the ProSEDS project with initial risk identification of all subsystems and continues throughout the project's life cycle through the disposition and tracking of existing and new risks. An assessment of technical and programmatic risks, as well as potential mitigation techniques, is part of the ongoing risk management of the ProSEDS project and is implemented by the ProSEDS Project Manager and Lead Systems Engineer.

The ProSEDS Project is an experiment funded on a fixed budget by the Pathfinder Program Office. ProSEDS is manifested as a secondary experiment on an expendable launch vehicle, a Delta II second stage. With a limit on the cost, size and weight of the experiment most of the subsystems are single string. With regard to safety, the project will be in full compliance with all Delta and Range safety requirements. No risks will be accepted that impact compliance with these safety requirements. With regard to mission success, a set of criteria has been developed to meet the primary and secondary mission objectives, see Table II. Risks that impact meeting primary mission objectives will have higher priority for mitigation than those risks that impact secondary mission objectives.

To mitigate risks to mission success, the ProSEDS project is using subsystems with flight heritage where appropriate, and is testing both at the subsystem and system level as much as possible on the ground. The ProSEDS technical team includes experienced personnel and uses regularly scheduled team meetings to discuss and disposition issues that affect the project. A clear set of objectives for mission success have been defined and communicated with the ProSEDS Team, and all system and subsystem requirements flow down from these mission objectives. All requirements are documented in the Requirements, Verification, and Compliance (RVC) database with all changes to these requirements communicated to the appropriate team personnel. Extensive up-front planning for the project was conducted and resulted in a successful proposal to the Future-X NRA 8-22. Project implementation is done with the proposal as the basis for the project. A summary of risks and mitigation strategies are listed in table below:

RISK ELEMENT	MITIGATION STRATEGY
Development Risk	
Electrodynamic Tether current collection	Extensive testing and development of alternative coatings
Operations Risk	
Tether Lifetime	Completing all primary mission objectives in the first day of operations
Battery Recharging	Operate using primary battery for first 3 orbits
Management Risk	
Cost	Budgeted Cost Reserves. Descope plan to preserve primary mission objectives
Schedule	Use of mainly existing hardware; mature development; availability of December 2000 backup flight

In addition the ProSEDS project will continually evaluate, document, and communicate project risks and plans to mitigate them. Team reviews will be held to implement a continuous process that:

- identifies risks
- analyzes their impact and prioritizes them
- develops and carries out plans for risk mitigation, acceptance, or other action
- tracks risks and the implementation of mitigation
- supports informed, timely, and effective decisions to control risks and mitigation plans
- assures that risk information is communicated among all levels of the project

Risk identification by team members, independent reviewers, and management personnel will be encouraged by the Project Manager and the Lead Systems Engineer. Communication of any project risks will be communicated both internally with the ProSEDS team, but also to appropriate management levels. Solutions to risks that are identified will be worked with the appropriate project personnel.

Should the project require descoping, a team, led by the Lead Systems Engineer and composed of the MSFC Lab Representatives, PI, a representative of the Smithsonian Astrophysical Observatory, and other participants assigned by the Principal Investigator will be formed to recommend descope options based the prioritized ProSEDS Objectives List. The team's recommendations will then be reviewed by the Project Manager for action.

XVI. ENVIRONMENTAL IMPACT

An environmental impact assessment shall be developed by the MSFC Environmental Engineering and Management Office.

XVII. SAFETY

A. System Safety

MSFC S&MA will perform a system hazard analysis to verify system compliance with the safety requirements specified in EWR-127. This analysis will be documented in the Missile Systems Prelaunch Safety Package in the format specified in EWR-127, Chapter 3. A closed loop tracking of each hazard will be performed.

B. Industrial Safety at MSFC

The MSFC Industrial Safety Office (ISO) is responsible for conducting a MSFC wide program for mishap prevention in all activities. The ISO responsibilities include facility and equipment safety inspections, surveys of safety program compliance, hazardous operations monitoring, development of Industrial Safety Program Requirements, and mishap investigation.

In the event of mishap, the requirements of MM 1040.3, MSFC Emergency Planning, and MMI 1711.2, Mishap Reporting and Investigation, will be observed.

XVIII. TECHNOLOGY ASSESSMENT

The ProSEDS initial technology that will be demonstrated is the validation of the operation of bare electrodynamic tethers in space and their utility for thrust operations. The flight will also serve as a demonstration flight of the technology for inclusion on the space station as an alternate reboost technology.

XIX. COMMERCIALIZATION

Many of the technologies to be demonstrated have direct commercial application. The most likely is the ability of a relatively small tether system to deorbit spacecraft and satellites at end-of-life. Additional commercialization of electrodynamic tether propulsion for upper stage applications is likely following the mission.

XX. REVIEWS

A. Management Reviews

Management Reviews will be scheduled during the life of the project. The type and frequency of the reviews will be established according to the unique needs of the project and the Program Office . The reviews will be scheduled to keep program and project management informed of the current status of existing or potential problem areas. Agency management will be informed, in advance, of the schedule and agenda of the major reviews and will be invited to participate at their discretion. Special reviews by any level of management will be conducted when the need arises. Management reviews will be held with the ASTP Manager and Future-X/Pathfinder Program Manager, as required.

Progress reviews will be scheduled as appropriate and will include the participation of all NASA Centers involved in the ProSEDS Project. The reviews will cover the overall status information and will include schedule status, change status, performance status, interface coordination, and other management and technical topics.

B. Technical Reviews

Informal technical reviews will be scheduled during the life of the project. The following reviews, as a minimum, will be held:

1. Preliminary Design Review (PDR)

A Preliminary Design Review was held to review the system design and requirements. Because the experiment is utilizing previously built parts from past flight projects (SEDS) and commercial off-the-shelf items, the review committee consisted of a few key members.

2. Critical Design Review (CDR)

Critical Design Review will be held to finalize the design, provide authority to procure or fabricate remaining flight hardware, and conduct a review of the system interfaces.

Other Reviews

Project personnel will support Delta launch reviews as required.

XXI. TAILORING

The requirements of NASA Policy Directive (NPD) 7120.4A and NASA Procedures and Guidelines (NPG) 7120.5A apply to this program as tailored by ASTP and the Future-X/Pathfinder Program Plan and this Project Plan.

XXII. CHANGE LOG

EFF. DATE	STATUS	DOC. REVISION	DESCRIPTION
Apr 28, 1999	Baseline		Original Issue
Dec 13, 1999	Re-baseline		Re-Issue